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# SHADOWGRAPH AND REFERENCE SYSTEM FOR A COMBINED WIND TUNNEL AND BALLISTIC RANGE


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# SHADOWGRAPH AND REFERENCE SYSTEM FOR A COMBINED WIND TUNNEL AND BALLISTIC RANGE

By Alfred G. Boissevain

The following notes describe briefly the proposed shadowgraph system for a new hypervelocity free-flight facility now under construction at the Ames Research Center of the NASA. The testing unit consists of a shock-tube-driven wind tunnel superimposed on a ballistic range. Light gas guns will propel models at velocities of up to 30,000 ft/sec against the airstream which can have velocities of up to 20,000 ft/sec. There will be two such test units: one with an 80-foot-long test section for aerodynamic stability tests and another with a 20-foot-long test section for radiation studies. Sixteen orthogonal shadowgraph stations will be used in the aerodynamic tunnel and four in the radiation tunnel to define the position and attitude of the model along its trajectory.

The optical system to be used is a folded "Z" focussed shadowgraph arrangement similar to the units presently installed in the prototype facility. Focal lengths of the spherical mirrors are all 75 inches. There are two sizes of windows, 15-inch and 12-inch diameter, resulting in values of $f/D$ of 5.0 and 6.25, respectively.

The problems involved in photographing a radiating model travelling at very high speeds are common to all ballistic ranges. The radiation from the gas cap and products of ablation are particularly troublesome since there is considerable overlap in the spectral distribution of the model radiation and the usual spark gap light source used to photograph the model, although the spark does have a greater concentration of light in the blue end of the spectrum. The solution to this problem used in our existing facility is sketched in figure 1. A folded "Z" focussed shadowgraph system is used with an aperture at the focal point of the collecting mirror. The film and the tunnel centerline are placed at conjugate foci of the collecting mirror. Any radiation from the model is attenuated by the ratio of the aperture area to the cross-sectional area at the aperture station of the light from the model collected by the mirror system. This approach has been generally satisfactory for the present test conditions which have, happily, included low ambient densities in the free stream. The physical system is fairly soft, however, and adjustment of the apertures must be made before each run. There have been occasions when shifting of the system after adjustment has produced vignetting or a partial schlieren effect, depending on the position of the aperture relative to the spark image. Enlarging the aperture to compensate for movement of the system increases the fogging from model radiation.

An alternate approach to reduce the effect of model radiation using lasers as light sources was investigated. Since the light from a laser is highly monochromatic, a low bandpass optical filter placed ahead of the film would block out most of the radiating light from the model. The fundamental flaw in this system stems from the fact that the outputs from lasers in the short exposure times desired - on the order of 20-50 nanoseconds - are not uniform over the surface of the lasing rod, although the integrated output over several microseconds does present a smooth appearance. Figure 2(a) shows the output of a

Trion laser as photographed with an Abtronics image converter with a 20 nanosecond exposure time. The light from the laser was passed through a collecting lens and then collimated with a 5-inch-diameter lens. A piece of tape was placed in the field to serve as a target and focussed on the image converter with a third lens. The background light is quite unacceptable for photographic use. The field shown is only a portion of the total. Figure 2(b) shows the output of a Hughes Kerr-cell-triggered laser, also photographed with the Abtronics image converter. In this case the image converter was simply placed in the divergent field downstream of the first collecting lens. The quality of the background has been much improved over the first case, but is still unacceptable. The rapid increase in laser technology will undoubtedly produce a useable laser in the near future.

The solution to the radiation problem being utilized in the new facilities is the use of a Kerr cell in place of the small aperture used in the folded "Z" focussed shadowgraph system. Attenuation of the light through the cell is a problem, but with the use of crystal polarizers in the Kerr cell the present spark units have sufficient light to expose Kodak Royal Ortho film at an exposure time of 30 nanoseconds and an image size of 7-1/2 inches diameter. The sparks have a total capacitance of 0.12 microfarad charged to 6000 volts.

Tests made on the transmissivity of an Electro-Optical Kerr cell with crystal polarizers showed a 40 percent transmission of the light through the cell with the polarizers in the open position. Sheet polarizers had a transmission of 11 percent.

Operating the Kerr cell at a short duration resulted in a surprising decrease in the effective exposure of the test film. It had been assumed that only the light in the upper third of the intensity versus time curve of the spark output was effective in exposing the film. Measurements of model blur reinforced this view. Based on this assumption, the effective duration of the sparks in use were between 100 and 200 nanoseconds. Exposure tests using the Kerr cell as a shuttering device showed that the ratio of film exposure was 35:1 between the unshuttered spark and one shuttered at 20 nanoseconds. The expected ratio on the basis of exposure times was 10:1. Exposures at 5 nanoseconds showed a ratio of 140:1 instead of the expected 40:1. These ratios indicate an effective duration of the unshuttered spark of about 700 nanoseconds. Figure 3 shows the trace of light intensity of the spark unit as a function of time as obtained with a photomultiplier tube. Note that at 700 nanoseconds after the start of the light pulse the intensity is almost back to zero. The ratio of total light energy between the unshuttered and shuttered spark, on the basis of the curve shown in figure 3, is about 25:1, which indicates that most of the light is effective in exposing the film.

A side benefit of the use of Kerr cells as a shuttering device is the short exposure times possible. It has not been possible to reduce the duration of the basic spark units below that shown in figure 3. As model speeds increase, it will become even more important to reduce the exposure time in order to get well-resolved photographs of the model, especially for shock-wave standoff distance measurements. As improvements are made in the peak intensity of the spark unit, it will be possible to shorten the exposure time from the present 30 nanoseconds, which gives a nominal blur of 0.011 inch at 30,000 ft/sec, to even shorter durations. An alternate trade-off for greater spark intensity is an increase in the magnification of the image recorded on the film.

The size of the light source has no effect on the quality of the shadowgraph if the film plane is focussed on the model plane. We are at present investigating the use of a simple lens to gather more light from the spark and project it towards the collimating mirror at the correct divergent angle. Although such a system increases the effective size of the source, gains of six times the useable light are possible for the present configuration.

The primary purpose of the photographic system is to provide information on the location and attitude of the model. In addition, however, information on the flow field around the model can be of great importance. In any shadowgraph system, the sensitivity to disturbances in the flow field is increased as the plate, or plane of focus in the focussed system, is removed from the plane of disturbance. Unfortunately, such a movement also erodes the quality of the model image, making precise measurements difficult. In order to have our cake and eat it too, some tests were made using a simple schlieren system which focusses on the model and also shows flow detail. The schlieren system was made by simply placing a knife edge at the image of the spark in the optical configuration shown in figure 1. Comparisons of observable flow detail were made with a shadowgraph system focussed 13-1/2 inches from the tunnel centerline. Shots from a 220 Swift were made into still air at various values of ambient pressure using two consecutive stations in the prototype tunnel for the shadowgraph and schlieren systems. The wake detail produced by the model was discernible at a pressure of 130 mm of mercury for both systems. At 10 mm of mercury the bow shock wave was just barely discernible, again for both systems. Reasonable care was taken to adjust the vertical knife edge in the schlieren system to the same sensitivity for each shot. It was surprising that the schlieren system did not provide better sensitivity. Some modifications were tried on the schlieren to improve the sensitivity, but without success, such as decreasing the diameter of the source and longer focal length mirrors.

The reference system used to define the position and attitude of the model is a duplicate of the system used on the prototype facility. The prototype system has the multiple virtues of ease of alignment, accuracy, and self-calibration. A sketch showing the salient features of the system is shown in figure 4. Nominal alignment and collimation of the light is obtained by simply adjusting the mirrors and the light source so that both windows and the second mirror are uniformly filled with light from the first mirror. The set of vertical plumb bobs shown in the example provide a measure of the collimation and alignment of the light, a vertical reference for angular measurements, and a reference for the magnification of the image. Figure 5 is a shadowgraph from a data run. In this case, the plane of focus was on the set of wires nearest the film; these are in focus while the pair on the opposite side of the tunnel are not. A shock wave is visible around the model, but there are no wake details. The model velocity was about 27,000 ft/sec.

The critical factors in the alignment of the system are the spacing of the pairs of wires on each side of the test section, the relative displacement along the X axis of the two sets, and the relative position of the sets of wires at one station with respect to the wires at the next station. It is possible to show that measurements of the images of these wires, used in conjunction with the known physical dimensions, can define the position of a nonmoving object to within 0.003 inch. It is recognized that the finite time of exposure will cause blur in the image of the moving model, but in practice the uncertainty is far less than expected due to the ability to read the film to the same relative position of the blurred image.

The vertical stations will be referenced in basically the same manner, with the exception that the reference wires will be long catenary wires common to all the stations rather than the plumb wires just described for the side stations. The reference for "z" displacements will be a catenary wire visible in all the side stations, corrected at several stations by the end tubes of a multi-legged manometer visible at the stations and photographed with the model and the rest of the reference system.

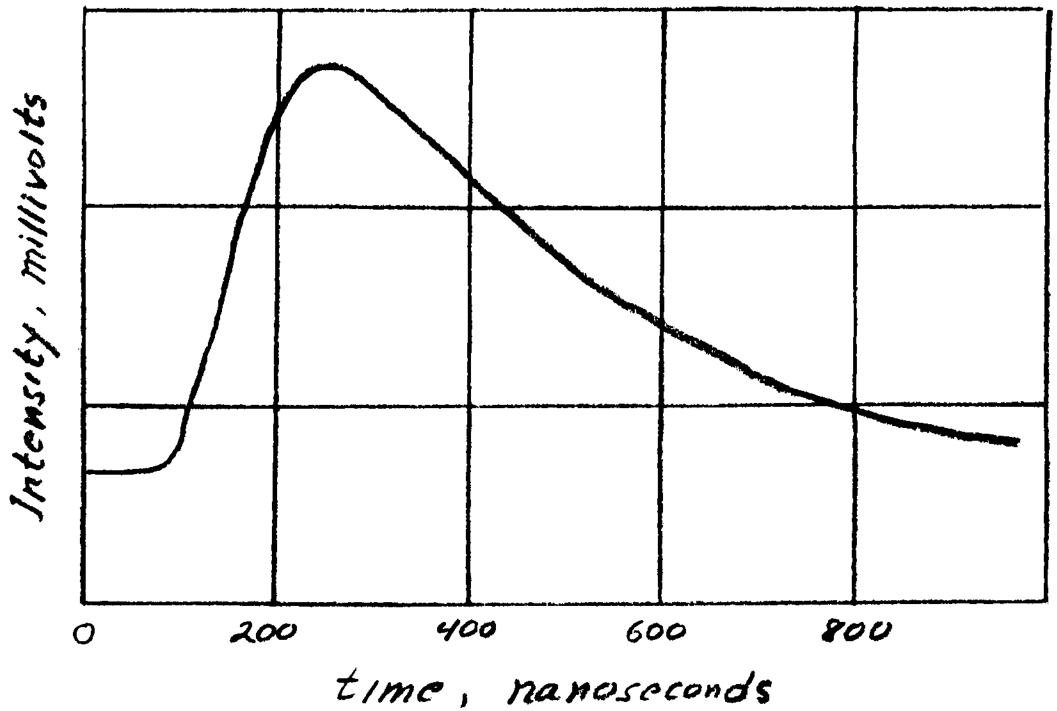


Figure 3.- Spark Gap Light Output.

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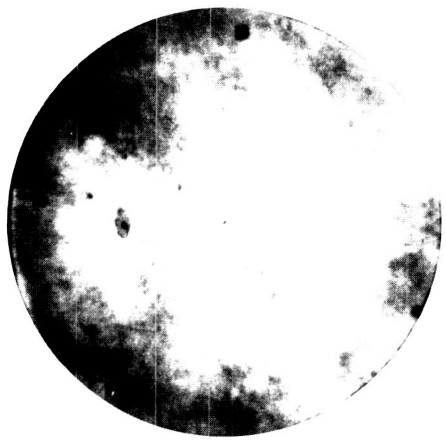
FIGURE - 2.

LASER LIGHT FIELDS AT 20 NANOSECONDS EXPOSURE
TAKEN WITH ABTRONICS IMAGE CONVERTER



TRION LASER

HUGHES KERR CELL
"Q" SPOILER LASER

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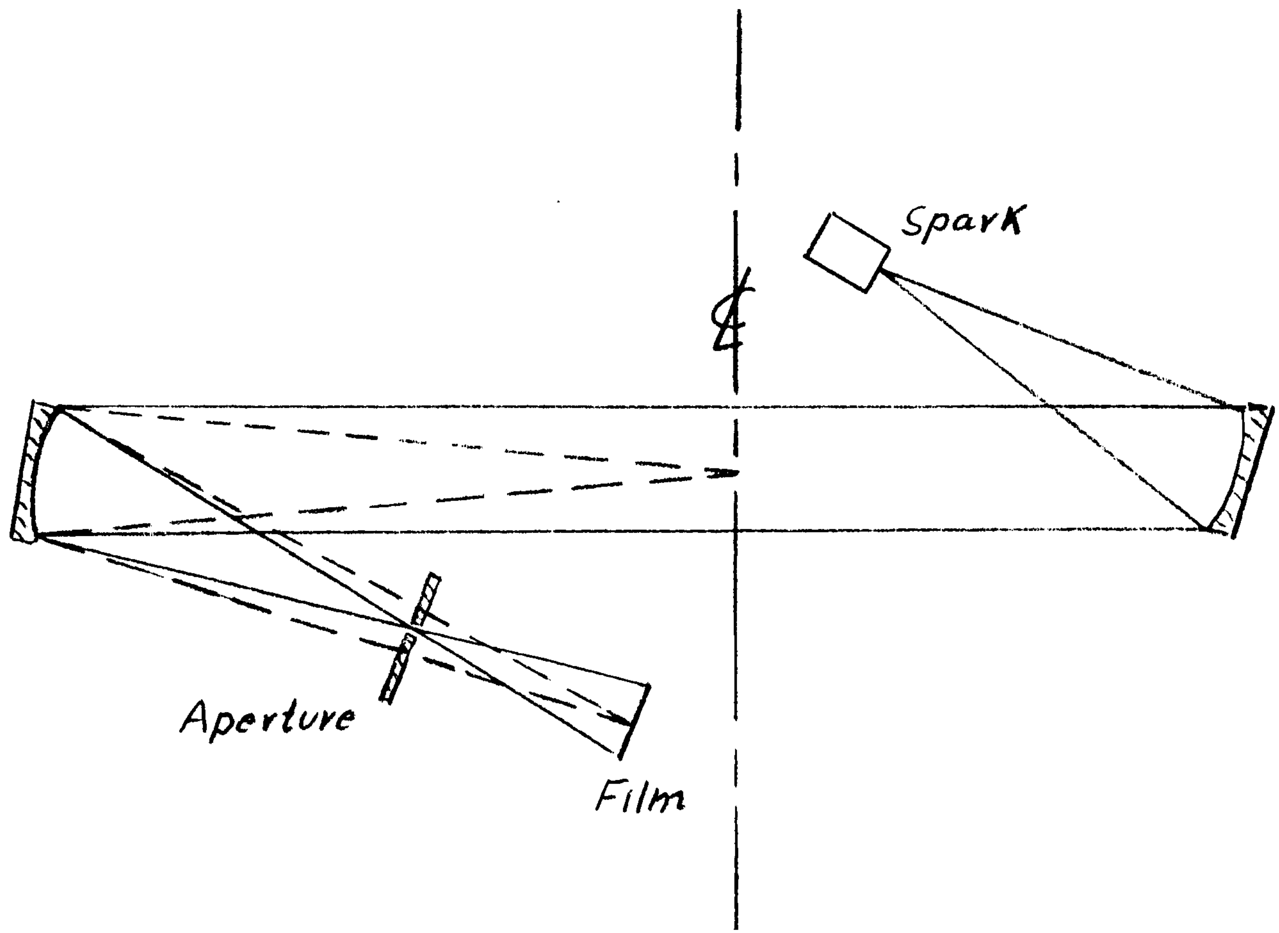


Figure 1.- Folded "Z" Focussed Shadowgraph System.

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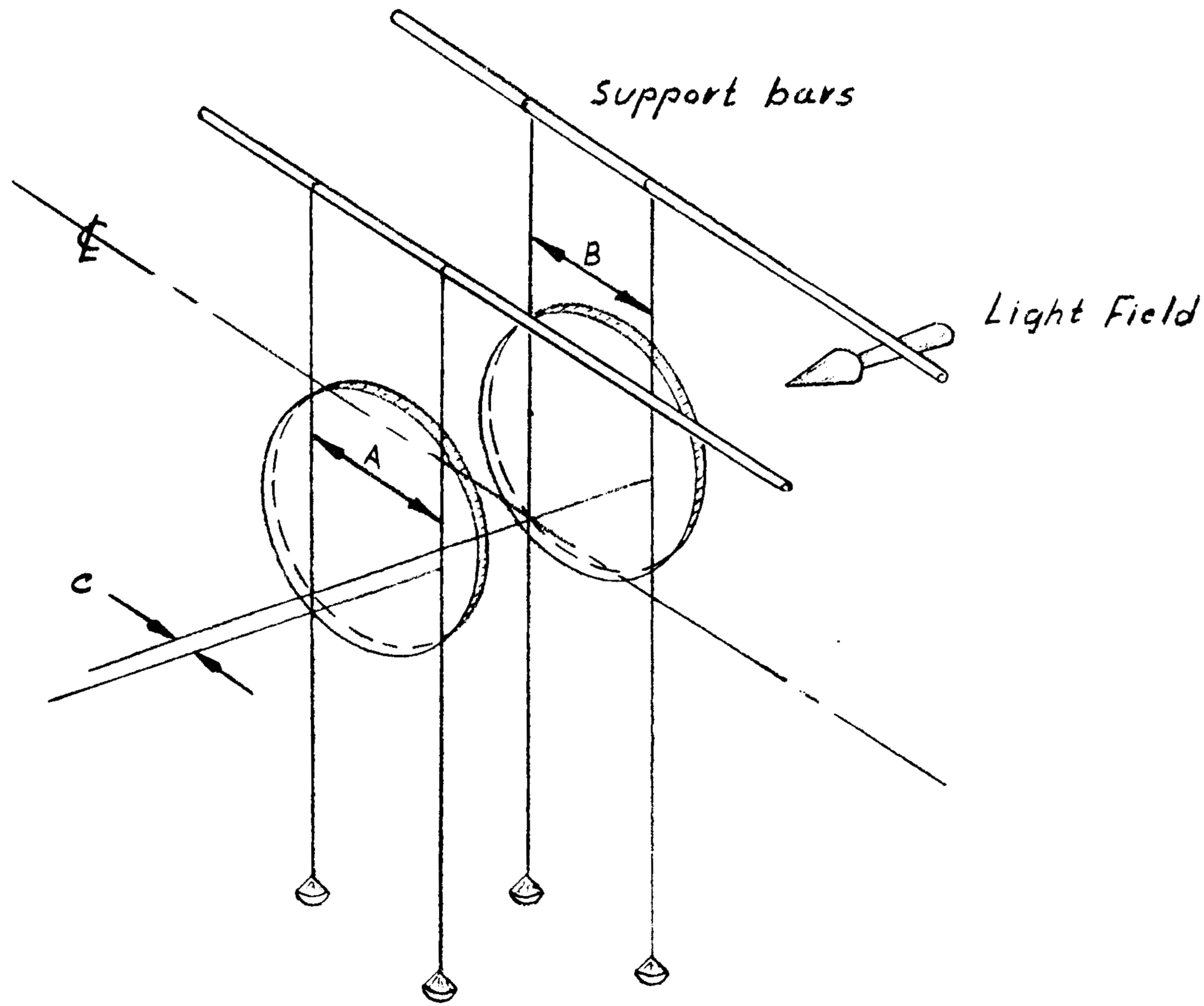


Figure 4.- Sketch of Reference System for Prototype Facility.

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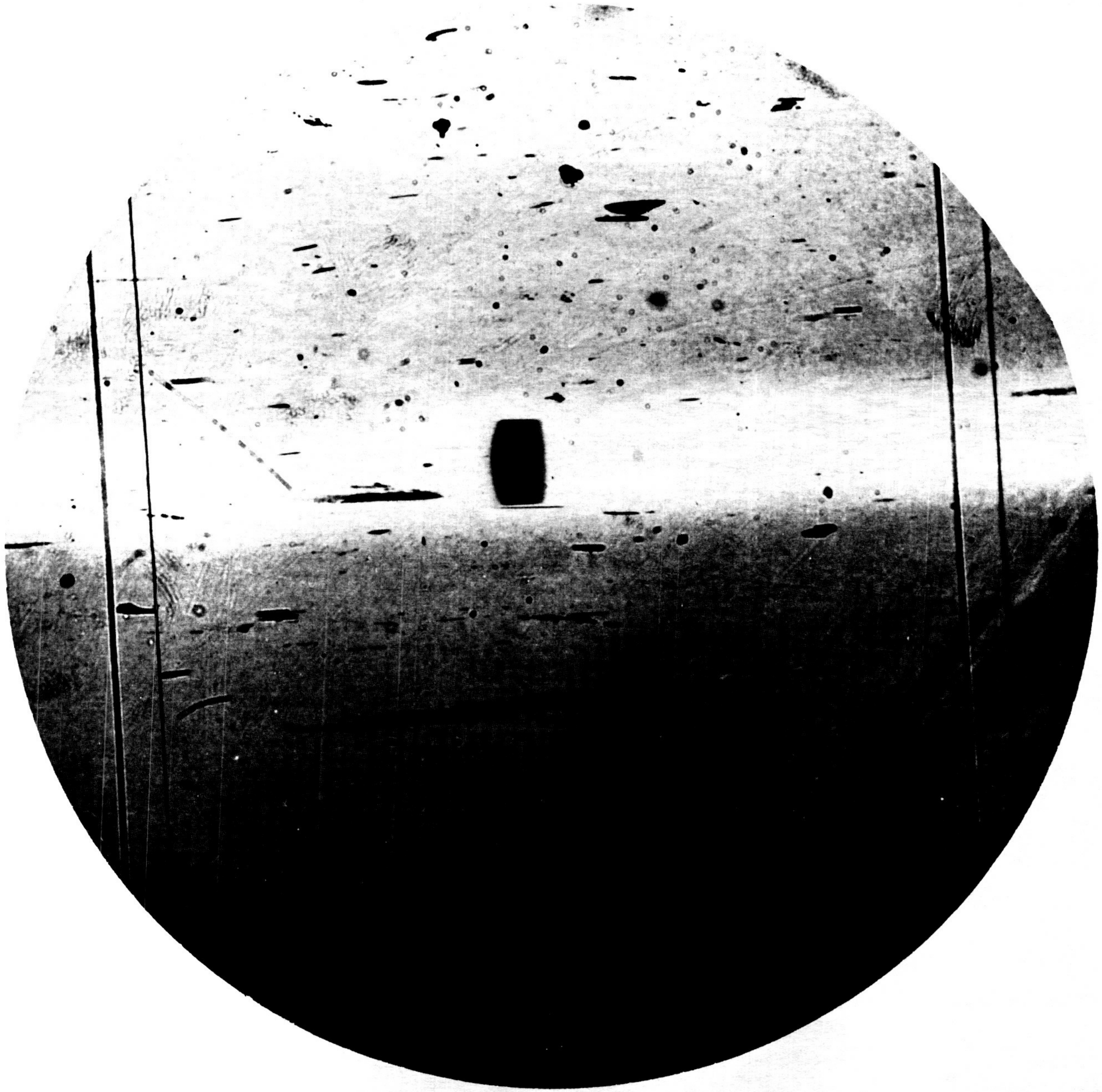

Figure 5. - Shadowgraph of model in flight.
$V_{total}$ 10.5 km/sec $V_{model}$ 8.3 km/sec $P_\infty$ 15 mm Hg.

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